WG4.4 (Contributed)
4:30 PM – 4:15 PM

A Novel Receiver for Spectrally Efficient Direct Detection Optical OFDM

S. Alireza Nezamalhosseini[1,2], Lawrence R. Chen[1], Qunbi Zhuge[1], Mahdi Malekiha[1], Farokh Marvasti[2] and David V. Plant[1]
[1] Department of Electrical and Computer Engineering, McGill University, Montreal, QC H3A 0E9 Canada
[2]Department of Electrical Engineering, Sharif University of Technology, Tehran, Iran

Abstract: We propose and experimentally demonstrate a receiver structure for direct detection optical orthogonal frequency-multiplexing systems that improves the spectral efficiency by reducing the guard band between the carrier and the OFDM signal while mitigating signal-signal mixing interference.

1. Introduction

Coherent optical orthogonal frequency division multiplexing (CO-OFDM) attracts considerable interest to provide per channel data rates exceeding > 100 Gb/s. On the other hand, direct-detection OFDM (DD-OFDM) has also gained attention for applications in long-reach passive optical networks and optical communications due to its simpler receiver structure and lower cost compared to CO-OFDM. In DD-OFDM, the transmitted signal is recovered by detecting the carrier and signal mixing products [1] in a square-law photodiode (PD). However, the desired mixing product is affected by the signal-signal mixing interference (SSMI). Several methods have been proposed to minimize the penalty due to SSMI. For instance, in offset single-side band OFDM (OSSB-OFDM) [2], a guard band (GB) equal to the OFDM signal's bandwidth is allocated between the optical carrier and OFDM signal such that the SSMI and desired spectra are nonoverlapping. The spectral efficiency (SE) of OSSB-OFDM is half of that in CO-OFDM. To increase the SE, several methods such as an iterative detection approach [3], and subcarrier modulation with turbo coding technique [4] have been proposed. These two approaches provide reasonable SE, but they require high computational complexity at the receiver. In this paper, we propose a simple novel receiver structure that improves the SE in DD-OFDM systems while minimizing the impact of SSMI.

2. Principle of operation

The principle model of the proposed receiver structure is shown in Fig. 1. The received signal can be expressed as

$$r(t) = H_{TF}(f_0)e^{j(2\pi f_0 t+\phi(t))} + \beta e^{j(2\pi(f_0+\Delta f)t+\phi(t))} \sum_{k=0}^{N-1} a_k H_{TF}\left(f_0 + \Delta f + k\frac{B}{N}\right) e^{j2\pi k\frac{B}{N}t} + n_{ASE}(t), \quad (1)$$

where $H_{TF}(f) = H_O(f)H_T(f)H_{CD}(f)$ denotes the overall transfer function from the transmitter to the receiver, and $n_{ASE}(t)$ represents the amplified spontaneous emission (ASE) noise as complex circular AWGN. We denote the frequency responses of the optical fiber, and optical filters as $H_{CD}(f)$, and $H_O(f)$, respectively. f_0 is the main optical carrier frequency, Δf is the GB between the main optical carrier and the OFDM signal, β is the scaling coefficient that describes the OFDM signal strength related to the main carrier, $\phi(t)$ is the phase noise, a_k is the OFDM information symbol for the kth subcarrier, and kB/N is the frequency for the kth subcarrier where B is the OFDM signal bandwidth and N is the number of data subcarriers. In the proposed receiver, an optical coupler splits the received optical signal into two parallel branches. The optical signal in the upper branch is sent to the PD directly. But, the optical signal in the lower branch passes through an optical filter to remove the optical carrier. Consequently, in the upper branch, the optical carrier and OFDM signal are present, while in the lower branch only the OFDM signal exists, i.e., the output of the PD in the upper branch consists of the dc, desired, and SSMI terms while the output of the PD in the lower branch consists of only the SSMI term. Thus, by simply subtracting the output of the upper branch from that of the lower branch, the SSMI term will be removed as

$$q(t) = q_U(t) - q_L(t) = |H_{TF}(f_0)|^2 + 2\beta Re\left\{e^{j2\pi m\frac{B}{N}t} H_{TF}^*(f_0) \sum_{k=0}^{N-1} a_k H_{TF}\left(f_0 + \Delta f + k\frac{B}{N}\right) e^{j2\pi k\frac{B}{N}t}\right\}, \quad (2)$$

where * represents the complex conjugate and Re{x} denotes the real value of x.

3. Experimental and simulation results

We investigate the system performance of the proposed technique both numerically and experimentally. The experimental setup is depicted in Fig. 2(a). The original binary pseudo-random bit sequence (PRBS) data is first divided and mapped onto 97 frequency subcarriers with 4-QAM modulation format and then transferred to the time-domain by an IFFT of size 512 while zeros occupy the remainder subcarrier. A cyclic prefix of 32 samples is used, resulting in 19.42 ns OFDM symbol duration. The generated inphase (I) and quadrature (Q) components of the OFDM signal are loaded separately on two field-programmable gate arrays (FPGAs) to generate the electrical I and Q signals via two digital to analogue convertors (DACs) operating at 28 GSamples/s; therefore, the data rate is 10 Gb/s. The analogue electrical I and Q signals are then fed into an IQ Mach-Zehnder Modulator (IQ-MZM) to

978-1-4577-1507-5/13/$26.00 ©2013 IEEE

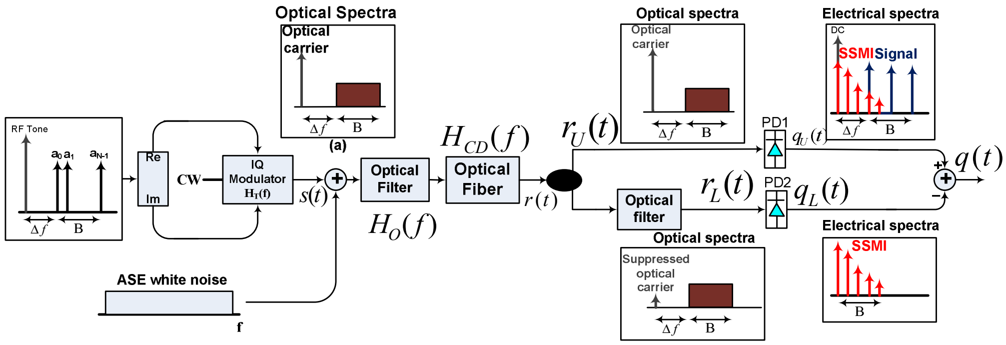
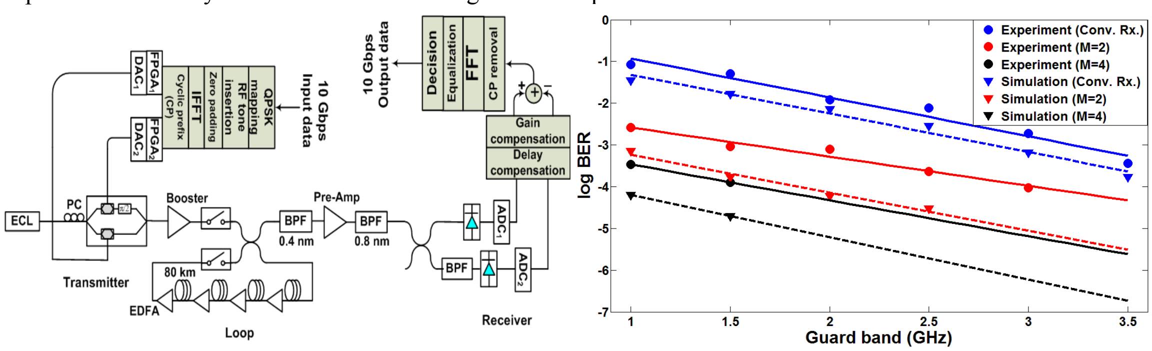


Fig. 1. Principle of SSB-OOFDM transmission and proposed receiver structure.

generate the optical OFDM signal. The modulated optical signal is transmitted through the four 80 km spans of Corning SMF-28e+ fiber. After each span, the signal is amplified by an Erbuim-doped fiber amplifier (EDFA) with a noise figure of 6 dB to compensate fiber losses. The received signal is fed into the proposed receiver structure where the signal is divided into two branches by a 50/50 coupler. The signal in the upper branch is sent to a PD directly, while in the lower branch the signal passes through an optical filter prior to PD. We consider two different optical filter orders. First, we use an optical filter with a second-order Gaussian response. By cascading another second-order Gaussian filter, a fourth-order Gaussian filter can be obtained. The converted photocurrents at each branch are electrically sampled and then recorded at 80 GSamples/s using a real-time oscilloscope (RTO). Signal processing is performed offline in MATLAB.

The bit-error-rate (BER) performance is depicted in Fig. 2(b) versus the GB for both simulation and experiment. The curves in the figure correspond to different receiver structures: conventional OSSB-OFDM receiver, and our proposed technique using second- and fourth-order optical filters. The dotted and solid lines correspond to the simulation and experimental results, respectively. The experimental results are in good agreement with the numerical simulations. The results show that using the second-order optical filter, the measured BER improvement varies from one to two orders of magnitude depending on the GB compared to the conventional receiver. An even greater improvement in BER can be obtained using a higher-order optical filter. The fourth-order optical filter improves the BER by about three orders of magnitude compared to the conventional receiver.



(a) (b)

Fig. 2. (a) Experiments setup. (b) BER versus guard band for simulation and experimental at an OSNR(0.1nm) of 16.8 dB after 320 km SMF transmission for 10 Gb/s data with a 4-QAM modulation.

4. Conclusions

We have proposed a novel receiver structure to improve the SE in DD-OFDM systems. The increased SE results in relaxing electronic components' bandwidth requirements in DD-OFDM systems. The experimental results show that proposed receiver is efficient to improve the performance of DD-OFDM systems. Moreover, the computational complexity is the same as that of the conventional receiver. For a 10 Gb/s data with a 4-QAM modulation using OFDM signal with 1.67 bits/s/Hz SE, the BER is improved approximately by three orders of magnitude compared to the conventional receiver when a fourth-order optical filter is used in the proposed receiver.

References

[1] B. J. C. Schmidt *et al.*, Journal of Lightwave Technology, Vol. 26, 196-203 (2008).
[2] W. Peng *et al.*, Journal of Lightwave Technology, Vol. 27, 5723-5735 (2009).
[3] W. Peng *et al.*, Proc. OFC'08, paper OMU1.
[4] Z. Cao *et al.*, IEEE Photonics Technology Letter, Vol. 22, 736-738 (2010).